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Canada Centre
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de la technologie
des minéraux
et de l'énergie

ROCK MECHANICS RESEARCH IN THE MINING RESEARCH LABORATORIES OF CANMET, 1964-1984

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A Submission to the Provincial Inquiry into Ground Control and
Emergency Preparedness in Ontario Mines

MICROMEDIA

MINERALS RESEARCH PROGRAM
MINING RESEARCH LABORATORIES
DIVISION REPORT MRP/MRL 85-19(TR)

ALPHABETIC

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INTRODUCTION

The "Canada Centre for Mineral and Energy Technology", known as CANMET, is the successor organization to the original Mines Branch of the federal Department of Energy, Mines and Resources. CANMET is presently comprised of five "line" Divisions and three "service" Divisions. The Mining Research Laboratories, one of the former, are the chief vehicles for the delivery of federal government hard rock mining research. Coal mining research and strata mechanics are the responsibility of the Coal Research Laboratories, with facilities in Sydney, Calgary, and Edmonton.

At present, the Mining Research Laboratories include four operating units. Three of these, the Rock Mechanics Laboratory, the Canadian Explosives Research Laboratory, and the Canadian Explosive Atmospheres Laboratory, are located at the Bell's Corners Complex in Nepean, Ontario. The fourth unit, the major field laboratory, is located at Elliot Lake. A new building, costing approximately five million dollars, is now under construction in Elliot Lake. The opening of the new facility is scheduled for late 1985.

The mission of CANMET is not only to provide advice of a technical nature to the Minister in respect of non-renewable resource policy decisions, but also to provide research which is supportive of that performed by industry and which serves government social and economic objectives. The operating Divisions are organized to correspond to the major sectors of the minerals industry, ie.: Coal (CRL), Energy (ERL), Minerals (MSL), Mining (MRL) and Physical Metallurgy (PMRL).

The policy objectives are accomplished through the provision of technical appraisals to the Department, through the transfer of technology both to and from industry, and through the provision of short-term and medium-term assistance in support of achieving particular goals. The latter may include the development of strategic technologies and provision of national facilities.

The research objectives of CANMET are accomplished through projects in three principal groupings. These are:

- (1) Policy research and development.
- (2) Protection technology R&D.
- (3) Productivity technology R&D.

Policy-related research includes not only the basic scientific and mining information that a government is expected to have, but also that which is required in support of policies, regulations, specifications and standards. Much of the research which is done in the Canadian Explosives Research Laboratory and in the Canadian Explosive Atmospheres Laboratory is in this group. Likewise, the work which is done concerning resource appraisals for strategic commodities also falls within this group. It should be added that CANMET, as the principal national mining research delivery agency, maintains contacts with Provincial inspectorates and plays a lead role in the development of standards through regulatory bodies and other organizations.

Protection technology research is that which is related to both protecting and improving the well-being of workers. Within the Mining Research Laboratories' structure the principal research thrusts are into mining health and safety and environmental protection. The former includes projects on ground control, dust, explosive atmospheres, exhaust pollutants, noise, and monitoring instrumentation (to list but the most prominent). The latter includes work at the Elliot Lake Laboratory in respect of minimizing the impact of, and rehabilitating, tailings ponds.

Productivity technology research, which is normally undertaken in either the short or medium term, has the most immediate commercial impact. Because of that, and the current economic situation, there have been strong pressures to direct an increasing part of the research effort into this area. It is certainly true that the greatest emphasis in MRL has been on protection technology while in the other CANMET Divisions the focus has been on productivity technology. In view of the particular missions of the Divisions, in relating to various sectors of the industry, that is not considered to be an abnormal situation. Nevertheless, it should be mentioned that the allocation of resources is based on known and perceived needs and that the process by which this is achieved involves vigorous discussions and debate.

Currently, an effort is being made to intensify productivity-related research in MRL. Both mining equipment technology and mining systems have been identified as prime areas. It must be mentioned, however, that mining processes cannot be replicated on a "pilot-plant" scale. Because of this, extraordinarily expensive full-scale field demonstration projects are probably indicated in selected cases. The costs of these, if implemented, will be very large indeed and will have a major impact on annual budgets.

While it is easy to state then, that more research of this type is required (and there is no argument with that), it must be borne in mind that the implications for planning and budgeting are substantial.

In any of the three groups of research interests, efforts range from the occasional provision of advice in response to special requests, to full-scale projects involving the establishment of national-level facilities. Both ends of the spectrum are relevant to the present inquiry since MRL not only has provided specialist advice on ground control matters on numerous occasions but also has suggested that research efforts concerning rockbursts should be intensified through the development of a coordinated national-scale approach.

HISTORY OF ROCKBURSTING IN ONTARIO

Rockbursts have been a "fact of mining" in Ontario mines for the past fifty-five years. Morrison, in his classic 1942 report (1), noted that occurrences had been intermittent since about 1928. From 1934 on, however, the increasing frequency became a cause of concern. During the last half of that decade there were, on the average, approximately 10 "heavy" bursts (involving 10 or more tons of rock) annually in each of the Sudbury and Kirkland Lake mining areas. When smaller events were included the average frequencies in each of the areas were increased tenfold. Morrison was engaged by the Ontario Mining Association in 1940 to study the growing problem. His report, in which he summarized some of the situations leading to rockbursts and methods of control, is still relevant to mining practices in many regards.

The potential for rockbursting increases with depth and the extent of mine workings. During the past fifty years, orebodies at greater depths have been exploited. Modern mechanization and bulk mining methods have resulted in much larger individual working places (stopes) and mining operations generally. Both of these trends must result in increased rockburst potential. Rockburst incidence statistics must, in many respects, reflect trends in mining activity in the various parts of the industry.

Since the original study, for example, rockbursting continued to be a common problem in the Kirkland Lake Mines. Many events during the 1960's and subsequently, some very large, were reported in the Lakeshore, Kerr-Addison, Dickenson, Campbell Red Lake, and Wright-Hargreaves Mines. The last-mentioned was closed after a major rockburst in the shaft pillar in 1964. Rockbursting continues to be a problem in the Red Lake, Kirkland Lake,

and Larder Lake Gold Mining camps. The incidence, however, is related to the fortunes of the gold mining sector.

Elsewhere in the Province, rockbursting has been a problem in both the Elliot Lake and Sudbury mining areas. In Elliot Lake, there were several rockbursts in the Stanleigh and Milliken mines before these were closed during the general decline in uranium mining in the early 1960's. It was only after the expansion of mining activities in the mid to late 1970's that rockbursting became a problem once again. At present, the great majority of the events are taking place in a worked-out and abandoned area of the Quirke Mine.

In the Sudbury area nearly all of the underground mines have experienced rockbursts to a greater or lesser extent. The older and deeper mines, such as Creighton, Falconbridge, Carson, and Levack, have been particularly affected. Events have also occurred, however, at the Copper Cliff North, Stobie, Onaping, and Strathcona Mines.

HISTORY OF ROCKBURST RESEARCH IN CANADA

In the academic community, rockburst research in Canada commenced with the arrival of R.G.K. Morrison at McGill University, in Montreal, in 1949. Through his keen interest in the subject a major research program in rock mechanics was initiated. Research in various topics in rock mechanics is in progress at several Canadian universities today.

Mining research at CANMET (then known as the Mines Branch) started in 1950 (2) with work on stress-release problems in the western coal mines of the Crows Nest area. Mining research was principally oriented towards coal for the first few years. By the mid to late 1950's, however, research was being increasingly oriented towards underground hardrock mines. A significant step in the development of hardrock mining research was the opening of the Elliot Lake Laboratory in 1964 and the establishment of the Mining Research Centre (now a Division), under Dr. D.F. Coates, in 1967. "ELL" continues to be the major centre for field-related rock mechanics studies. Its importance, in respect of applied rock mechanics and rockburst research will grow considerably as the result of initiatives which are presently being taken.

As a note, it should be added that all aspects of coal-related research were combined within the mandate of a new Coal Research Laboratories division (CRL), in 1982. Rock mechanics research for coal mines, which is not discussed in this report, is presently conducted in Calgary and Sydney.

CANMET'S ROCK MECHANICS RESEARCH 1964-1984

During the last two decades the Mining Research Laboratories of CANMET have been engaged in a broad range of rock mechanics activities; theoretical to applied and laboratory to mine sites. Over 350 research reports have been written during this period. The titles and authors of these reports have been broken down into 11 categories and are listed in Appendix A. These reports only cover research in underground hardrock mines, other reports on soft rock mining (coal, potash, salt) and open pit mining are excluded.

The highlights of this research, by category, are summarized below:

(a) Rock Testing and Classification

The mechanical properties of rock are an important input parameter for any stability estimation and computer modelling. It is fortunate that the Elliot Lake Laboratory obtained a 2000 ton capacity compression testing machine in 1965. This is still the largest machine of its kind in Canada. With it many investigations were done on the strength-size relationship for rocks from Elliot Lake, Wawa, Timmins and Sudbury. Recently, the machine has been converted to do stiff-testing in order to examine the post-failure characteristics of rocks. These are important in rockburst research.

Rock mass classification systems are increasingly being used to evaluate stope span stability and support requirements. Rock strength and properties of joints are an integral part of these classification systems. Early research in the 1960's was concerned with the strength, brittleness and the elastic/viscous behaviour of rock. More recent research has broadened the data base to include more field data on joint properties as well as the size and function of mine openings.

(b) Stress Measurements and Instrumentation

CANMET pioneered the introduction and development of stress measurements in Canadian mines. In 1965 measurements were started in the Elliot Lake mines using the United States Bureau of Mines deformation meter, followed by the South African Council of Scientific and Industrial Research "doorstopper" methods. In more recent years the South African CSIR triaxial strain cell and the Australian hollow inclusion strain cell have been tested. In conjunction with the test work, theoretical research was done on the calculation of stress and accuracy. By 1984, pre-mining field stresses have been

determined in all of the major mining camps in Ontario, as well as some in Manitoba and Québec. These measurements by CANMET were the first indication that, in the Canadian Shield, the horizontal stresses are invariably higher than the vertical gravitational stresses. This finding is of fundamental importance to mine design.

(c) Other Instrumentation

In the 1960's commercial rock mechanics instrumentation was very limited and much of the instrumentation used in the mines was manufactured in CANMET's workshops. Considerable research was done on multi-wire borehole extensometers, including their accuracies and limitations. The design guidelines which were issued for these types of instruments affected commercial instrumentation world-wide. Simple load cells manufactured for measuring load on rock bolts and timber sets are still in use today. For thin tabular orebodies convergence meters were designed which are now manufactured by the mining companies themselves. A common feature of all this instrumentation was that it was simple, rugged, inexpensive and disposable.

(d) Structural Geology

The disciplines of rock mechanics and structural geology were combined together in many of CANMET's projects. After measurements of high horizontal stress in the mines, regional structural surveys were undertaken to explain the tectonic history of the area. These studies started in Elliot Lake but also expanded to the Wawa and Timmins areas. On a more local scale structural investigations are undertaken on surface crown pillars, and the immediate hangingwall, to evaluate possible modes of failures.

(e) Modelling

Over the last two decades there has been a great change in modelling techniques used in rock mechanics. The physical, photoelastic, and pure mathematical models have largely been displaced by powerful computer models. Initially, 2-dimensional finite element models were used for determinations of stresses and displacements. These models became more sophisticated with time to include non-linear behaviour and 3-dimensional mining layouts. Displacement discontinuity models are used frequently for tabular deposits and the initial program has been improved by introducing compressible pillars and

backfill. Boundary element models are the simple elastic solution and the more complex multi-material model. Recent thrusts in modelling have been to convert programs from mainframe to mini and micro computers and improvements in graphical display of results.

(f) Support Systems

Initial research on rock bolting was done in coal and salt mines and led to the first tentative specifications for roof support. Further research was done on the use of cable bolting in both open pit and underground mines. Present studies are concerned with detailed evaluation of the interaction between the rock mass and support system and the time of placement of the support.

(g) Room-and-Pillar Mining

Most of the research in this area has been done in the Elliot Lake uranium mines. Stope-and-pillar design guidelines were formulated in the 1970's. Pillar stresses were estimated from depth below surface, extraction ratio, pre-mining stresses, and the dip of the orebody. Estimates of pillar strength were developed based on width, height and the strength of laboratory samples. These guidelines were checked against cases of both stable and failed pillars and was found to conform. Subsequently, the guidelines were up-dated to include multi-seam mining in the Elliot Lake mines.

A comprehensive survey of faulting and roof conditions was done at one mine. It was found that faulting was the major reason for altering stope-and-pillar layout and that bedding plane slips were the major cause of roof falls.

In cooperation with Rio Algom Limited and Denison Mines Limited an Elliot Lake Rock Mechanics Committee was formed to investigate regional stability. The first task of this committee was to formulate guidelines for mining activity for a distance of 250ft from the property boundary between two mines. Subsequently, computer studies were done on proposed pillar recovery operations. In 1984 local union members joined this committee.

(h) Cut-and-Fill Mining

Research on the use of backfill in mines started with laboratory testing of fill to determine strength and deformational properties and

percolation rates. This work continued with field testing to obtain in situ properties. Present research is towards optimizing both sand and rock backfill based on size distribution of the aggregate and cement content. Measurements of fill pressure and wall closure have been taken in a number of cut-and-fill mines to elucidate the functions of backfill as a support medium, and how it affects the amount of energy released due to mining. A number of review papers have been written on backfill mining practice and methods of transportation.

(i) Bulk Mining Methods

Most of the research in this area has been concerned with blasthole stoping in mines at Wawa, Timmins and Sudbury. Investigations have included stress measurements, rock displacement measurements and computer modelling. In recent years contracts have been given to consultants and mining companies to further this research including in situ field trials. Golder Associates have evaluated stable stoping spans at depth. INCO Limited investigated underground bulk mining blast design. Falconbridge Limited designed a bulk mining method for one orebody at their Onaping Mine and an actual mining trial is at present underway involving cable bolt support systems, special drilling and blasting techniques and monitoring of rock stability.

(j) Rockbursts and Seismicity

In the late 1960's CANMET was involved in a relatively small effort on rockburst research in both the Porcupine Mining Camp and in Newfoundland. With the closing down of many rockburst-prone mines, research was diverted to other areas. In the 1980's rockbursts again became a problem in many mines in northern Ontario. The major occurrences have been: At Quirke Mine in Elliot Lake in March 1982, then September 1984 and December 1984 to January 1985; at Campbell Red Lake Mine, in December 1983; Falconbridge Mine in June 1984; and INCO's Creighton Mine in July 1984. In all of these cases, CANMET scientists have been involved either serving on international technical committees to investigate the cause and mechanisms of the rockbursts or doing detailed technical case history studies. The use of microseismic monitoring and convergence measurements has also been reviewed.

(k) Textbooks and State-of-the-Art Reviews

"Rock Mechanics Principles" by the late Dr. D.F. Coates was the first textbook on rock mechanics used for teaching purposes in the world. It is now in its fourth edition, being revised in 1981, and has been translated into French, Spanish and Chinese. A subsequent publication on "Incremental Design in Rock Mechanics " has also received wide distribution.

CANMET scientists, because of their country-wide contacts with the mining industry, are often asked to write state-of-the-art reviews for both national and international conferences. These have included rock mechanics applications in Canadian mines, underground mining methods in Canada, and cut-and-fill mining technology in Canada.

PRESENT WORK OF THE MINING RESEARCH LABORATORIES

As mentioned in the Introduction, and shown in the organizational chart in Appendix B, the Mining Research Laboratories are one of the five research Divisions of CANMET. MRL is comprised of four laboratories, of which one is located at Elliot Lake and the remainder at Bells Corners, in Nepean, Ontario. A chart showing the distribution of resources among the laboratories is contained in Appendix C.

Of the laboratories, two, namely CEAL (Canadian Explosive Atmospheres Laboratory) and CERL (Canadian Explosives Research Laboratory), perform functions which are essentially in the categories of Policy and Protection research. Within CEAL, for example, much of the work relates to the certification of equipment for use in gassy underground mines and in product testing. In CERL, much of the testing work is in support of the Canada Explosives Act. Approximately 40% of the MRL professional, technical and support staff (about 30 persons) are employed in these two laboratories. While much of the work of CEAL and CERL relates to mining health and safety, none at present is in the areas of rock mechanics or ground control.

The geotechnical aspects of MRL's mission are addressed in both the Elliot Lake Laboratory (ELL), and the Rock Mechanics Laboratory (RML) at Bell's Corners. With the exception of a group dedicated to maintaining a national inventory of uranium reserves, very little of the work of either laboratory is within the category of "policy" research. Rather, the work is of a more applied nature and in support of productivity enhancement and protection.

At present, the projects being undertaken in the four laboratories are listed in the table which is given as Appendix C. These projects which relate directly to rock mechanics, and would therefore be of greatest interest to the Committee are, as follows:

(1) Potash Mining	2.15 PY
(2) Model Development	3.4 PY
(3) Mine and Regional Stability	4.0 PY
(4) Rock Mass Characterizations	3.2 PY
(5) Rock Properties and Support Systems	<u>2.15 PY</u>
	14.9 PY

Other projects, relating directly to mining health and safety are:

(1) Diesel Emmission Impact and Control	4.5 PY
(2) Radiation	3.9 PY
(3) Respirable Dust	3.2 PY
(4) Noise and Vibration	2.3 PY
(5) Environmental Monitoring and Control (CEAL)	<u>1.0 PY</u>
	14.9 PY

The above projects account for approximately 75% of the combined professional and technical staff in the Elliot Lake and the Bell's Corners Rock Mechanics Laboratory. Rock mechanics and health and safety topics have traditionally been the areas of the greatest strength in MRL.

Within the projects relating to rock mechanics, the current objectives are as follows:

(1) Potash Mining

By carrying out contract research with regard to Canadian potash mining in the areas of ground control, environment, and productivity, to increase current potash recovery (presently about 40%).

(2) Model Development

To develop investigational procedures, equipment and application methodologies leading to greater use of rock mechanics in mining in the area of mine modelling and mine structural analysis by:

- developing new computer models for evaluating stability of underground openings and related structures;
- upgrading/enhancing software packages and hardware capabilities for mining and geotechnical applications;

- conducting studies related to mining applications and by developing guidelines for designing underground openings.

(3) Mine and Regional Stability

The objective complements that of model development. Project work includes seismic monitoring, pillar stability, and rock stresses and strengths. The objectives will be realized:

- by investigating underground stability, including rockbursts, where high stresses are the major cause of failure;
- by studying, using instrumentation, empirical and computer models, alternative mining layouts and design which could alleviate failure.

(4) Rock Mass Characterization

The work of this project also complements the above mentioned:

- by investigating underground stability where geological structure and gravitational forces are the major cause of failure and by developing, empirical, statistical deterministic models to predict stable structures.

(5) Rock Properties and Support Systems

This work also contributes to the principal objective:

- by establishing, through theoretical and experimental studies, the requirements, procedures, techniques, and specifications for laboratory and field testing essential for underground mine design in terms of stability analysis and support system design;
- by evaluating the limitations and effectiveness of present and proposed support systems for use in deep mining, under high stress conditions;
- by carrying out laboratory investigations related to material model development and other projects.

SOME FUTURE DIRECTIONS OF MINING RESEARCH IN CANMET/MRL

Since the formation of the Mines Branch, in 1907, the Federal Government has carried out and sponsored research and development to address the needs of the public, industry, and government. CANMET is the principal research organization involved with mining research in Canada. The information presented in this report, which relates only to rock mechanics

research and to some aspects of related health and safety topics, is indicative of the deep and lasting commitment to such work by the organization.

Because it is only in the underground or open pit mines that the value of research can be ascertained, there is a continuing close association between the staff of the Mining Research Laboratories and their industrial counterparts. At the senior managerial level the research activities are guided by communications with senior executives, with national and provincial associations and organizations, and with the National Advisory Committee on Mining and Metallurgical Research (NACMMR). At all levels at which policies and directions are established, the intent is to ensure that the work of the laboratories is directed towards meeting national need.

It must be emphasized that it is not within the normal scope of the mission for the laboratories to undertake work of a "pure" nature - such work, which most-often addresses potential long-term needs, is best done in academic institutions. In essence, the Mining Research Laboratories should be seen as functioning as a sort of "safety net" for industry. The research and development work which is done should principally be that which addresses the immediate and medium-term needs of the industry, and which is beyond either the present capacity or ability of the industry to deliver.

Within recent years, the most outstanding example of MRL's work was the "Pit Slope Manual". This multi-volume manual, directed towards improving the design of open pit mines, resulted from a major research project which was initiated in the mid 1970's (by the late Dr. D.F. Coates, the Director of MRL, at that time). The work has had an enormous influence on both national and international open pit mine design practices and operating procedures. It has been shown (3) that the total cost of the project, which was approximately five million dollars, has been recovered several times over through increased efficiency and cost reductions.

At present, it is hoped that it may be possible to develop a similar series of manuals, applying specifically to underground mining practice, within the next few years. As the tremendous number of international visitors to Canadian mines attests, our underground mining practices and procedures are internationally renowned for their state of technological advancement. There is a need for the "Canadian experience" to be brought together into a major design manual.

Because of the current rock bursting problem which is facing the industry, there is no other area of underground mining practice in which present needs are more acute. MRL has recognized this for some time and has been working vigorously within the past year to encourage major research initiatives on this topic. A CANMET sponsored "Microseismic Workshop" was held in Sudbury, on August 14-15, 1984. The proceedings (4) are being published by CANMET as a special publication and will be distributed shortly. It is planned that similar workshops, or seminars, will be sponsored on a regular basis in order to promote the most rapid dissemination of new information and the transfer of technology.

In addition, it has also been proposed that a national centre for rockburst research be developed at the MRL Elliot Lake Laboratory. Discussions with industry and with the Government of the Province of Ontario have been taking place since about May of last year. These have resulted in the document "A Proposal for a Major Research Project on Rockbursts" which is appended to this report as Appendix D. MRL intends to intensify its efforts in rockburst research at the earliest possible opportunity. With some additional resources becoming available, efforts are being intensified.

Other actions which relates to an increasing commitment to mining research thrust on this topic are also taking place. In keeping with the most recent recommendations of the NACMMR Mining Sub-Committee, increased emphasis is being placed on mining technology. Within the past year two additional staff members have been appointed in this area, and a third has been re-assigned from another laboratory. For a small government research institution, these shifts represent very rapid and significant changes in focus. From the organizational chart which is appended, as Appendix B, it will be appreciated that, because much of the work of MRL is in support of both Policy and Protection functions, the opportunities for internal reallocations are somewhat limited. In order to intensify the work in certain areas, including rockburst research, incremental resources will be required.

The Mining Research Laboratories of CANMET, and particularly the Elliot Lake Laboratory, have long been known for the in situ work which has been done in support of industrial needs. As is indicated by the lists of publications given in Appendix A, many field investigations have taken place during the last twenty years. The emphasis on such work can only be increased as the result of the completion of the new laboratory facilities in Elliot

Lake, later this year. Projects to be addressed at ELL will relate principally to rock mechanics/ground control and to mining environments. Instrumentation for rock mechanics, which was one of the specializations of the laboratory for a long period, is an area in which research is being both rejuvenated and intensified.

At present, a number of Mineral Development Agreements (MDA's), within the overall frameworks of Economic Regional Development Agreements (ERDA's), have been concluded between various provincial governments and the federal government. From the point of view of MRL, the agreements provide an opportunity to address the most pressing needs of particular regions. Taken collectively, the work which is performed, if well co-ordinated, can represent a significant expansion of the national level research thrust.

In that context, it should be noted that major rock mechanics and ground control studies are about to be initiated as the results of agreements which have been concluded in the provinces of New Brunswick and Manitoba. In both instances, the projects have been determined after a consultative process between government research officials from the respective political jurisdictions, and representatives of the local industry.

In New Brunswick, during the next five years, the sum of \$400,000 will be expended on ground control studies which relate particularly to the new potash mining industry in that province. The work will complement that which MRL has co-ordinated in Saskatchewan, through the START program (Short-Term Aid for Research and Technology), in the past two years. Even though the START program is now being concluded, an effort is being made to continue some work in the western potash mines and to develop a permanent MRL research program which relates directly to potash mining. Both the START program and the MDA's are providing an opportunity to initiate highly-focussed research to meet specified industrial objectives.

In Manitoba, the MDA discussions resulted in a much larger sum being allocated to mining research. The part which MRL will undertake to deliver during the next five years will cost \$1.6 million. At the same time, the Manitoba government will also assume the responsibility for delivery of other research in the mining technology area.

Most of the studies will relate to ground control and rock

mechanics. The projects are as follows:

1. Federal Government (MRL) Delivery

- (a) Communications System for Isolated Areas in Mines, Especially in Orebodies Composed of Multi-lenses.
- (b) Design Guidelines for the Vertical Block Mining Method, for Steeply-Dipping Orebody.
- (c) Development of a Geomechanical Data Base for Ground Control in Underground Mining.
- (d) Evaluation of Methods for Delayed Backfill Consolidation.
- (e) Ground Stability Evaluation, with Particular Reference to En-Echelon Orebodies.
- (f) Optimization of Blast Design for Blasthole Mining Operations.

2. Manitoba Government Delivery

- (a) Underground Computer - Assisted Design.
- (b) Mine Air/Water - Waste Heat Recovery.
- (c) Secondary Recovery of Base Metals by In - Place Leaching.
- (d) Overburden Stabilization.

At present, Mineral Development Agreements are being negotiated in other provinces, including Ontario. Discussions with representatives of the industry have resulted in the identification of areas of research priority. The proposal for a major project on rockburst research, which is appended, resulted from a meeting held at the Northbay Hotel, in Sudbury, on Wednesday, May 9, 1984. MRL hopes to be able to receive the approval to extend its present efforts at the earliest possible opportunity.

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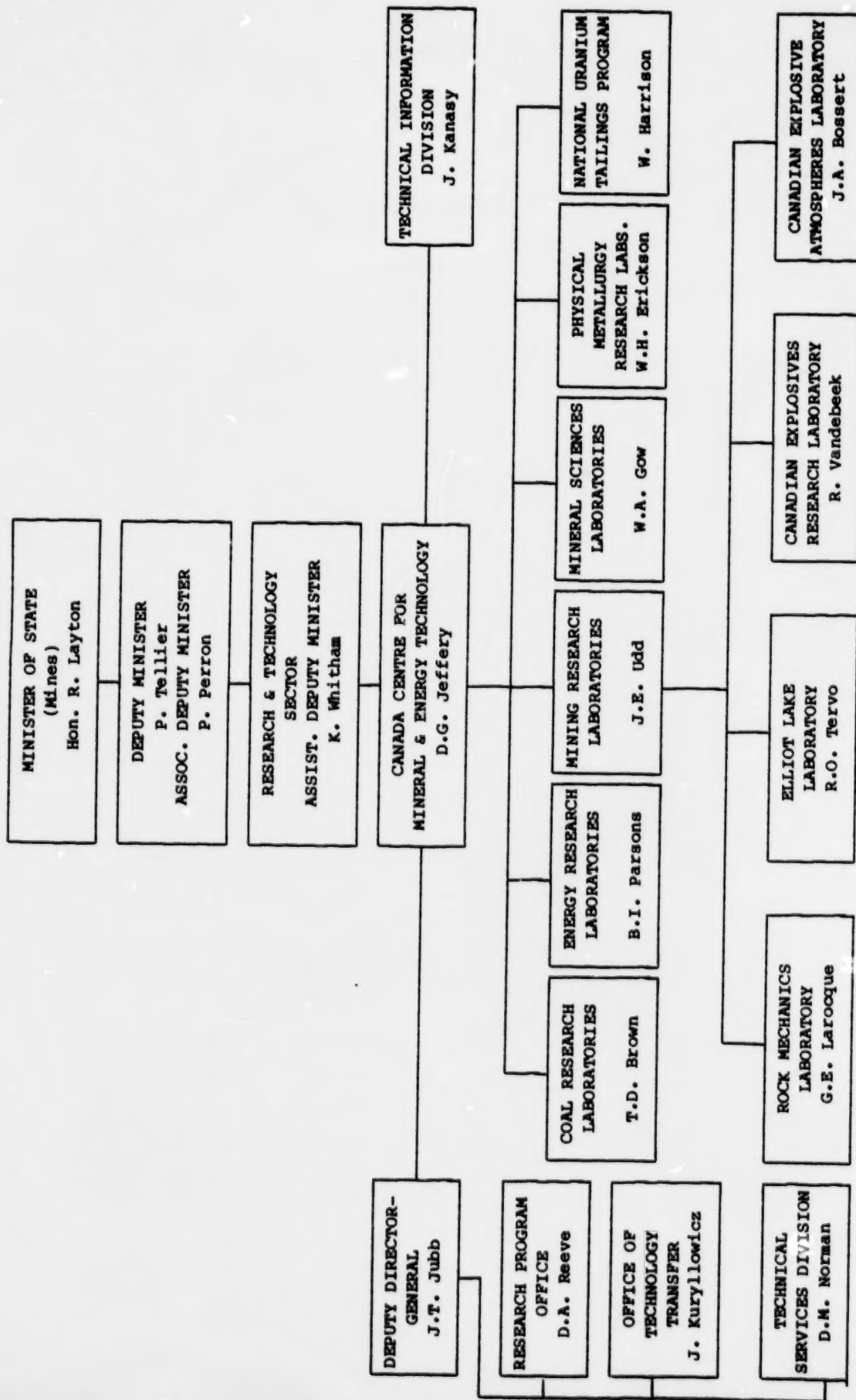
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APPENDIX B
ORGANIZATION

ORGANIZATION CHART - ORGANIGRAMME



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APPENDIX C

MRL RESOURCES AND PROJECTS
84/85

**DISTRIBUTION OF RESOURCES
MINING RESEARCH LABORATORIES
1984 - 1985**

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<u>PERSON YEARS (by Laboratory)</u>	<u>HQ</u>	<u>RML</u>	<u>CEAL</u>	<u>CERL</u>	<u>ELL</u>	<u>TOTAL</u>
Professional	2	18	7	7	14	48
Technical	0	3	5	8	8	24
Admin. Support	4	1	1	1	4	11
	<u>6</u>	<u>22</u>	<u>13</u>	<u>16</u>	<u>26</u>	<u>83</u>
<u>PERSON YEARS (by Activity)</u>						
Explosives	0	0	0	13	0	13
Minerals	2	10	3	0	26	41
Energy	4	12	10	3	0	29
	<u>6</u>	<u>22</u>	<u>13</u>	<u>16</u>	<u>26</u>	<u>83</u>
<u>BUDGET (\$K)</u>						
Explosives AOM	0	0	0	53	0	53
Capital	0	0	0	33	0	33
Minerals AOM	73	35	33	0	183	324
Capital	9	10	10	0	327	356
Energy AOM	117	82	98	20	0	319
Capital	33	70	71	72	0	214
						<u>1299</u>
Construction Cost of New Elliot Lake Laboratory		Operating Budget for 1984/85				3230
						<u>4529</u>

MINING RESEARCH LABORATORIES - PROJECTS

<u>Project No.</u>	<u>Project Title</u>
<u>220100</u>	<u>EXPLOSIVES TECHNOLOGY</u>
<u>220101</u>	Certification & Technical Advice
<u>220102</u>	Explosives R&D
<u>310100</u>	<u>MINING METHODS AND EQUIPMENT</u>
<u>310101</u>	Equipment Development Technology
<u>310102</u>	Interaction of Equipment and Mine Design
<u>310103</u>	Canadian Mining Technology Coordination
<u>310104</u>	Potash Mining
<u>310200</u>	<u>ROCK MECHANICS</u>
<u>310201</u>	Model Development
<u>310202</u>	Mine & Regional Stability
<u>310204</u>	Rock Properties & Support Systems
<u>32100</u>	<u>MINE ENVIRONMENT</u>
<u>210101</u>	Diesel Emission Impact & Control
<u>320102</u>	Radiation
<u>320103</u>	Respirable Dust
<u>320104</u>	Noise & Vibration
<u>320105</u>	Environmental Monitoring & Control (CEAL)
<u>350100</u>	<u>TAILINGS MANAGEMENT</u>
<u>350101</u>	Tailings Management to Minimize Environmental Impact
<u>430100</u>	<u>COAL RESERVES ASSESSMENT</u>
<u>430101</u>	Coal Reserves Assessment (MRL)
<u>430400</u>	<u>COAL MINE HEALTH AND SAFETY R&D</u>
<u>430401</u>	Coal Mine Health & Safety R&D
<u>430450</u> <u>ERD</u>	<u>COAL MINE HEALTH AND SAFETY R&D</u>
<u>430451</u>	Coal Mine Health & Safety R&D (ERD)
<u>430500</u>	<u>COAL MINE SAFETY CERTIFICATION</u>
<u>430501</u>	Equipment Safety Certification
<u>440100</u>	<u>URANIUM RESERVE AND ASSESSMENT</u>
<u>440101</u>	Uranium Reserves & Production
<u>440200</u>	<u>URANIUM MINE EVALUATION</u>
<u>440201</u>	Mine Operations Evaluation
<u>440300</u>	<u>NUCLEAR WASTE DISPOSAL</u>
<u>440301</u>	Underground Nuclear Waste Repository
<u>390400</u>	<u>MANAGEMENT AND ADMIN. SUPPORT (MINERAL)</u>
<u>390401</u>	Management & Admin. Support
<u>460400</u>	<u>MANAGEMENT AND ADMIN SUPPORT (ENERGY)</u>
<u>460401</u>	Management & Admin. Support

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APPENDIX D

A PROPOSAL FOR A MAJOR RESEARCH PROJECT ON ROCKBURSTS



Energy Mines and
Resources Canada

Energie, Mines et
Ressources Canada

D-45

CANMET

Canada Centre
for Mineral
and Energy
Technology

Centre canadien
de la technologie
des minéraux
et de l'énergie

APPENDIX D

A PROPOSAL FOR A MAJOR RESEARCH PROJECT ON ROCKBURSTS

John E. Udd

MINING RESEARCH LABORATORIES

December 1984

MINERAL RESEARCH PROGRAM
MINING RESEARCH LABORATORIES
DIVISION REPORT MRP/MRL 84-84 (TR)

A PROPOSAL FOR A MAJOR RESEARCH PROJECT ON ROCKBURSTS

by

John E. Udd*

ABSTRACT

Rockbursts, such as occur in the Canadian pre-Cambrian Shield, are attributed to stress redistributions which accompany mining in hard rock formations. Microseismic activity, which accompanies the stress increase preceding rockbursts, is viewed as having the potential to locate areas in which rockbursts may occur and, perhaps, to provide a means of short-term prediction prior to occurrence.

Although microseismic systems have been used experimentally in mines for many years, marginal advances in methodology and equipment development have limited their use. This is attributed in part to mine utilization philosophy, staff turnover, and the limited market for equipment which could be developed.

Source location is the objective of the existing, or planned, ten Canadian microseismic systems. The research on rockbursts which is proposed would involve investigation, development and testing of equipment and methodologies directed at improving the location of microseismic build-up, identifying the mechanisms of energy release, and, in some cases, warning of impending rockbursts.

The first phase of the proposed research would consist of three elements: studies at two Sudbury mines using extensive conventional state-of-the-art microseismic systems; studies with an advanced prototype system permitting detailed seismic event analysis at an important Ontario mine; and local area mine monitoring trials at several other small mines with a basic microseismic system.

* Director, Mining Research Laboratories, Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources Canada, Ottawa, Ontario.

This proposed research on microseismic systems would be carried out over a five year period. Details on the proposal are provided in the text with respect to technical approach, research plan, specific objectives, benefits, cost, schedule and management structure. The total cost of the first phase, is estimated at \$4,200,000.00.

The second phase of the work would involve trials to determine the effects of bulk mining methods, with various forms of backfill support, on local and regional stability conditions.

The cost of this second phase, involving bulk mining trials with associated microseismic monitoring, is estimated at \$2,000,000. This phase would either follow the first, or would be commenced in the fourth or fifth year of it; depending on the development and availability of suitable monitoring systems.

The overall objectives of the proposed project are the following:

1. To improve the interpretation of microseismic signals, and the accuracies of determining microseismic source locations.
2. To improve evaluations of the effects of mining methods on local and regional stability conditions.
3. To develop leading-edge scientific capabilities in Canada, and to foster the spread of that technology throughout the industry.

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BACKGROUND

THE SIGNIFICANCE OF THE PROBLEM

A rockburst is a sudden, violent release of energy. It is a natural consequence of loading a hard, brittle, elastic material to the point of failure. Over the last two years, fourteen mines in Canada have experienced rockbursts.

A recent, and very tragic, event occurred in Canada at Falconbridge Limited's Falconbridge Mine (No. 5 Shaft), on June 20, 1984. In that instance a very severe rockburst caused the failure of the back (roof) of an undercut-and-fill stope. The resulting collapse of fill killed four miners. The long-lasting effects were the closure of the mine and the subsequent disruption to the work of some 400 men.

A further series of major seismic events, the largest of which attained a magnitude of 4.0 on the Richter scale, took place at Inco's Creighton Mine on July 6. Fortunately, a summer vacation shutdown was in effect at the time and no injury resulted from the damaged rock underground.

More recently, commencing on December 17, a series of rockbursts occurred in a burst-prone area of the Quirke Mine, in Elliot Lake. During the first two days of the renewed activity over 400 seismic events were detected. The largest of these attained a magnitude of 3.5 on the Richter scale. As happened on previous occasions, mechanics working in the area of the Denison number 1 shaft, some 500 meters away, expressed reservations about returning to work.

Because the effects of rockbursts can be devastating in both human and economic terms it is imperative that we use all of the means at our disposal to reduce the possibilities of the tragedies, injuries, and major dislocations that would be caused by other occurrences.

Fortunately, from a scientific point of view there is some promise that a solution can be found. In particular, the accurate determinations of locations of sources of microseismic occurrences may provide the key to both the locations of highly-stressed areas and the possibility of short-term prediction of events. Detailed analysis of wave forms may provide clues to the causes and mechanisms of rockbursts.

Microseismic emissions, which are usually in the ultra-sonic frequency range result from the propagation of cracks in brittle materials.

There is considerable evidence that the frequency of such microcracking increases as the level of applied stress is changed. Thus, the number of events may provide some measure of the level of stress which is applied.

In the laboratory, even when the samples of rock are very small, the cracking and the sudden explosion of a test sample can be impressive. In mines, the release of energy and cracking are on scales which are orders of magnitudes greater. For anyone who has experienced loud cracking or rockbursts underground, the effects are awesome.

STATUS OF CURRENT TECHNOLOGY

Unfortunately, very few advances have been made in application of microseismic technology to rockburst predictions. At present, after 40 years of equipment development and refining of techniques, there is still a large element of uncertainty in the handling of field data.

However, the reasons for this become more apparent. First, the scale of underground operations may be very large, thus necessitating major instrumentation programs with corresponding higher costs. Many companies, because of this, choose "target areas" for instrumenting - and in so doing, accept the risk that events may be outside of the sensor array. Such was the case with some of the recent rockbursts in Sudbury.

Second, in mining it is very common for individuals to progress rapidly through the managerial and technical ranks. Because of this, the experience gained by a skilled worker is easily lost through relocation or career progression. From a national point of view it is lamentable that there is a lack of microseismic specialists in mining. This situation is not likely to be rectified until specialists with the expertise have been developed and provided with the incentives to remain in the field.

Third, because experience in Canada has not been translated into a clearly applicable technology, microseismic equipment development has not paralleled equipment development in other fields. The market for microseismic equipment is very limited and there has been little financial incentive for manufacturers undertaking the essential technological developments in microelectronics or data processing.

Since field work began in the 1940's, a methodology based on geophysical techniques has been used. Geophones, arranged in a three-

dimensional array to surround possible events, are used to detect signals. Because underground mines are often extensive, it can be appreciated that an array of any significant size can require miles of wiring. The times at which an event is detected at several geophones are used to calculate the original position of the disturbance.

In current practice the arrival of a first signal at any geophone in an array "opens a time window" for calculation purposes. The arrival of other pulses at a number of other geophones within prescribed time limits (as an example: at 5 geophones within about 50 milliseconds, or 1/20 second) is taken as confirming that a real event has happened within the volume enclosed by the array. The time interval selected is usually that which would be required for a sonic wave to pass through an array diagonally (i.e., the greatest distance between geophones). Having satisfied the criteria that an event is valid, the location is calculated from the arrival times. The use of arrival times at all of the geophones at which an event was detected, in various combinations, provides redundancy which is useful in assessing accuracy. After calculations, the original data is "dumped". This precludes any further analysis.

Unfortunately, geophones are indiscriminate. All sources of noise in a mine, therefore, may trigger the calculation sequence. Routine blasting, equipment operating, normal drilling, and even conversations may be detected by geophones. A large element of judgement is required in the selection of a "threshold value" below which events will not be recorded. No matter what level is selected, there will probably be legitimate events which will not be recorded.

At present, some 10 microseismic systems, with varying degrees of sophistication have been, or are being, installed in the following Canadian mines:

1. Inco, Creighton Mine	64 sensors
2. Falconbridge Mine	16 sensors
3. Campbell Red Lake Mine	48 sensors
4. Rio Algom, Quirke No. 2 Mine	24 sensors
5. Potash Corp., Cory Mine	32 sensors
6. Denison Mine	8 sensors
7. East Malartic Mine	16 sensors (now removed)
8. Rio Algom, Stanleigh Mine	16 sensors (planned)

- | | |
|-------------------------------------|----------------------|
| 9. Lockerby Mine, Falconbridge Ltd. | 32 sensors (planned) |
| 10. Brunswick, Noranda | 32 sensors (planned) |

All mine operators planning to install and use microseismic systems, however, are faced with essentially the same difficulties and problems. These were described as follows in a CANMET-sponsored workshop for industrial workers which was held in Sudbury, Ontario, on August 14-15, 1984 (note, a list of participants is attached as Appendix "A"):

1. There is a need for an approach, and system, which can be used to assess the influences of mining methods and practices. At present, microseismic monitoring is considered the best approach to large-scale or mine-wide monitoring (as opposed to local small-scale monitoring, which is used in conjunction with assessing the stabilities of individual stopes, or work places).
2. A difficulty with this approach is that microseismic activity begins to occur in hard and brittle rocks only when stresses have increased to the point at which failure begins to occur. Because the margin between the onset of seismic activity and a rockburst may be very narrow, the accuracies and sensitivities of systems are of great concern.
3. In the interest of improving the accuracy in both locating the sources (of events) and determining the energies involved, practitioners are looking for both improved equipment and practical techniques. The evaluations of equipment on a comparative basis (which has not yet been done, for cost reasons) might result in significant technical advances.
4. Equipment manufacturers should be encouraged to accelerate the development of "state-of-the-art" technology. This is difficult at present since the market is small.
5. Because of technical difficulties, the predictability of events is not feasible at present. While the locations of burst-prone areas can be established, warnings can not be provided of the timing of probable events. Predictability in both time and space, however, must remain as a long-term goal.

TECHNICAL APPROACH

At present, the systems installed in Canadian mines involve a number of geophones and a processor. Analysis of data is based upon the time of first arrival of a seismic wave at each detector in the array. In general, the very first arrival of an event above a preset threshold value causes a "time window" to be opened. If a sufficient number of arrivals is detected by other geophones within the limits of the "time window" it is assumed that an event has occurred, and calculations are effected. A rapid series of events, however, such as those that occurred at Inco Metal's Creighton Mine on July 6, 1984, can be lost for purposes of recording and calculations. Because the system may be saturated with data, subsequent events may not be detected.

Historically, present systems have been developed from those which were used by mining engineers for detecting and locating single events. The development of equipment which can be used more successfully vis-a-vis multiple events is a matter of high priority.

With present systems only the channel numbers and the times of first arrivals are recorded. Significant improvements in accuracy, as regards event detection and source location, could be effected through waveform analyses. At present, any source which produces a noise above the threshold level (such as blasting, equipment operating, drilling) can cause a microseismic system to be activated.

The analysis of waveforms is considered to be the best approach to achieving differentiation between the causes of waves. If successful this would lead to considerable purification of data. This is also the only avenue of approach which would permit an assessment of source mechanisms for events. If successful in this respect, the resulting improvements in the sensitivities of systems would lead to a much greater understanding of the effects of mining on the surrounding rock mass. Fortunately, even though the approach recommended is more involved, microprocessing hardware is available which can be used to effect a very high degree of automation.

Also at present, it is common for the processing unit to be located underground, and the printer on the surface. Because of this the analogue signals are lost for purposes of further analysis.

In the present approach, then, it is proposed that the processing units be located on surface. While the primary function of the monitoring

systems will not be compromised, it will then be possible to do much more in the way of further analyses of signals. Analogue-to-digital conversions will be achieved by multi-channel interfaces on microcomputers. Filtering of extraneous interferences, alternative source location techniques, development of generalized event signatures, and the determination of the energies of various source mechanisms, are examples of further analyses that would be attempted. Sophisticated computer systems for signal and data analysis will be required.

As analytical techniques are developed at one or more central facilities, these will be implemented at the dedicated computer systems and the mines. The scheme will enable continual updating of monitoring techniques in the industry.

RESEARCH OBJECTIVES

The specific objectives of this proposed research project are the following:

1. To improve safety in underground mines.
2. To move closer towards the identification of areas or zones within mines in which seismic events (or rockbursts) are likely to occur.
3. To develop improved equipment and analytical techniques.
4. To increase an awareness in the industry of the effects of mining practices and sequences upon stabilities of the surrounding rock mass. This is particularly relevant to the newer large-scale bulk mining methods.
5. To increase Canadian capabilities in microseismic monitoring, and to develop a "National Centre of Excellence", in this respect, within the Mining Research Laboratories.

The achievement of these objectives will involve research:

6. To examine the waveforms of the signals resulting from a number of different, and known, events; with a view towards the recognition of characteristic event signatures.
7. To compare the signals originating in two distinctly different mining operations, with a view towards obtaining a better understanding of source mechanisms and of the differences (if any) between the resulting signals.

8. To develop methods by which extraneous signals may be removed from recorded data.
9. To effect improvements in the accuracy of determining the locations of events, and the energies released. The first questions asked by an operator after a seismic event are inevitably: "Where was it?", "How big was it?"

ANTICIPATED BENEFITS

If successful, this proposed research project will have the following potential benefits:

1. Result in increases in the sensitivities of microseismic monitoring systems, thus leading to a greater understanding of the effects of mining (and particularly those of large-scale bulk mining methods).
2. Through waveform analyses, result in improved accuracy in locating seismic events and the calculation of the energies involved.
3. Result in techniques by which the many interferences at present may be removed from the records and separated from the seismic data.
4. Result in a much greater understanding of the basic mechanisms and of the causes of rockbursts.
5. Lead towards the development of both improved equipment and techniques.
6. Represent a significant step forward towards the ultimate goal of being able to identify not only the areas in which rockbursts are likely to occur, but also, in as many cases as possible, to provide warnings.
7. Result in the development of Canadian expertise in microseismic monitoring and rockburst detection.

RESEARCH PLAN

RESEARCH DESIGN AND MILESTONES

The research program is comprised of three elements. These are:

- (1) Detailed monitoring at two mines in Sudbury, Ontario.
- (2) Evaluation of microseismic systems that are more sophisticated than those in Canada at present.

(3) Local monitoring trials in other mines.

(1) In the first of the elements it is proposed that both of the systems presently installed in mines in the Sudbury basin should be improved to reflect the best of "state-of-the-art" technology. In both cases the processing units are presently underground, and should be relocated on surface to permit the more sophisticated processing of data which are gathered. Computer systems, for on-site analyses of data, are also required, as are adequate on-line storage capabilities in order to prevent "buffer overloading" of the systems during a major event.

It is a particularly noteworthy feature of this element of the work that one of the systems to be upgraded is located in a mine which was recently closed after a series of major rockbursts. The second is located in what is probably the country's "flagship" nickel-copper mine.

At first glance, the above approach may seem to involve needless duplication. The scientific reasons, however, are compelling. These are:

1. The mechanisms causing rockbursts in each of the mines are believed to be different. In the case of the recently closed Falconbridge Mine, it is believed that slippage along faults was the basic mechanism. In the case of Inco's Creighton Mine, which also experienced severe bursting recently, it is believed that seismic activity was due to the breaking of rock during the propagation of a caving zone and the crushing of pillars.
2. In the case of the work proposed for the Falconbridge Mine, it should also be expected that results of a unique nature will be obtained. The mine, even though closed, will remain accessible as a route for the transportation of ore underground from the East Mine for possibly two years.

In this instance, the work represents an unparalleled opportunity to obtain "pure" microseismic data against a background of no mining noise. Hopefully, any signals obtained will permit very precise analyses of the signature waveforms resulting from the fault-slip mechanism.

The milestones which would reflect progress in (1) would be:

1. The completion of the upgrading of both systems.
2. The obtaining of recognizable signature signals for each of the mechanisms causing rockbursts.

3. The relocation of the system at Falconbridge No.5 Shaft to another mine upon the successful conclusion of (2). (Note: this would be arranged by mutual consent, as maintaining the system of No. 5 Shaft once the basic information sought has been obtained, would serve no useful research purpose.)
4. The development of techniques which could be used to separate extraneous signals from legitimate microseismic data.
5. The demonstration that improved methods of determining locations and calculating the energies involved have been achieved.

(2) In the second of the elements it is proposed that one of the more elaborate seismological systems which is available should be purchased and installed, for the purpose of making comparative evaluations, at Inco's Creighton Mine.

The particular feature of such systems that justifies a purchase is that each channel is equipped with a microprocessor (as opposed to one for an entire system). The net result is that analyses which reflect the highest degree of sophistication may be effected.

It is visualized that the results to be obtained, in waveform identification and the determination of sources, will be of a uniquely high quality.

The milestones, while very similar to those which would result from (1), and in fact, being complementary, would also include:

1. The installation and calibration of the seismological system.
2. The obtaining of recognizable waveform signatures which could be related to various events (including those caused by mining activities such as drilling and blasting).
3. The development of techniques for the "purification" of microseismic data.
4. Demonstrations that the techniques are resulting in improved accuracy.
5. The resulting up-grading at other operating Canadian mines.

(3) In the third element, a conventional microseismic monitoring system would be purchased and installed at mining operations, other than the two mentioned, for periods of up to two and a half years per installation.

Rockburst phenomena have also been experienced at several of the hardrock mines outside of the Sudbury area. Many of the companies involved do

not have microseismic systems because of both the costs and the specialized skills that are required. The objectives of this part of the work would be not only to assist other operations in the evaluation of the effects of local mining practices but also to gather additional field results which would add to the breadth of the overall study.

Initially, research would be concentrated on the problem of rockbursts in crown pillars of steeply-dipping narrow vein deposits (e.g., Campbell Red Lake, Dickenson, Macassa). This is the most common type of rockburst in Ontario. The research team would also investigate why rockbursts are rare in similar mines in the Timmins area.

The milestones which reflect progress would be individual reports in which the results of local studies would be given. These should appear at the rate of a least one per year.

ESTIMATED COSTS

The cost estimates which are given are based on the knowledge that a significant part of the expenses would be borne by the operations at which research would be conducted.

It is also certain that assistance would be received through collaboration with the Ministry of Labour of the Province of Ontario, and with other bodies (such as the United States Bureau of Mines).

To illustrate this point, the Ontario Ministry of Labour is also pursuing microseismic monitoring initiatives (for emergency preparedness purposes), and has generously offered to provide occasional use of office facilities, in Sudbury, and technical collaboration.

In the case of the studies in Sudbury, both Inco and Falconbridge have already invested in Electro-Lab Monitoring systems. Including the costs of equipment and installation, Inco has expended in excess of \$200,000. Falconbridge, with a much smaller system has probably invested in the range of \$100,000.

In the present proposal, it is assumed that the costs of new additional equipment, supplies, and the provision of some technical support, would be provided through federal and provincial contributions. The costs in respect of local installations of geophones and other units, and the provision of technical backup, would be provided by the individual companies participating in the project.

Thus with respect to element 1 the equipment costs are estimated to be:

- (i) Upgrading Inco Creighton system
 - Cable.....\$ 40,000
 - Electronics.....\$ 25,000
 - Computer system for data analysis.....\$ 30,000
 - (ii) - Provision for computer to be used with
 - Falconbridge system.....\$ 30,000
 - Subsequent expansion of system, up to full
64 channel capability, at another
Falconbridge Mine, estimated at.....\$100,000
- Equipment costs for element 1 \$225,000**

With respect to element 2, the equipment costs are estimated to be:

- (i) Seismological system.....\$500,000
 - (ii) Data Processing Equipment and other
Electronic Equipment for use with the
above unit.....\$300,000
- Equipment costs for element 2 \$800,000**

With respect to element 3, the equipment costs are expected to be:

- (i) Microseismic system with computer, for mine
rockburst monitoring.....\$ 75,000
 - (ii) Equipment for two to three installations
(\$100,000/installation).....\$300,000
- Equipment costs for element 3 \$375,000**
- Total equipment costs \$1,400,000**

These costs are probably accurate to within about ten percent
(1984 dollars)

To this, must be added the cost of technical support to be provided by CANMET. It is assumed that the team developed for this particular project would become members of the permanent staff complement - thus achieving the objective of developing a national centre of excellence.

The staff required, and the direct salary costs are estimated as follows:

- (i) Seismologist.....\$ 50,000/annum
- (ii) Ground Control Eng.....\$ 40,000/annum
- (iii) Electronics Technician.....\$ 35,000/annum

(iv) Support Technician, for field and workshop..\$ 35,000/annum

(v) Secretarial and administrative support.....\$ 20,000/annum

Direct Annual staff costs (excluding benefits) \$ 180,000

CANMET staff cost for project \$ 900,000

To the above CANMET project expenditure a sum of \$40,000 per annum should be made available for travel and accommodation, and a further sum of \$50,000 made available to cover the costs of staff hands-on training (in South Africa and in the Coeur d'Alene area of the United States of America).

Total CANMET travel and training and on-site

accommodation costs for project.....\$ 250,000

A further sum of \$250,000 will be required for the replacement, maintenance and operation of portable (including mobile equipment). Audio-visual equipment to be used for technology transfer purposes, and costing approximately \$15,000, is included in this estimate \$ 250,000

Total costs for staff, (excluding benefits)

travel and training..... \$1,400,000

During the project, both Inco and Falconbridge would each be expected to provide a full-time technician to the project, at estimated annual costs of \$40,000 per company. A further amount, estimated at \$1,000,000 would be required from these companies and others in the province, to cover part of the costs of local installations (including local living expenses). These potential contributions remain to be negotiated..... **\$1,400,000**

Thus,

The grand total cost for the entire first phase of the

project is estimated at..... \$4,200,000

(being \$1,400,000 each for: Equipment, staff, travel, training, installations).

The costs which are shown have been developed on the basis that other indirect, but substantial, contributions to the project would be made by the industry. An actual value cannot be assigned to these at present.

WORK PLAN: Phase 2

Finally, as mentioned, it is recommended that the first phase of the work, as described previously, should be followed by a second phase involving studies of the effects on stability of bulk mining methods (with various filling alternatives). From this perspective, some five years in advance, it is not possible to establish a budget for this aspect of the work. Nonetheless, a preliminary rough estimate of \$2,000,000 is not considered to be unreasonable.

WORK PLAN: Year 1

During the first year of the project, the equipment for the upgrading of the system at the Creighton Mine would be purchased and installed. At the same time, the Falconbridge system would be improved through the addition of an on-site computer.

By the end of the first year the project team should have been recruited and appointed. Either the seismologist or the ground control engineer should have received foreign hands-on training in the use of systems elsewhere (or should be close to the completion of that training - estimated at 6 months). A visiting scientist should have been appointed to CANMET on a sabbatical basis and would be in the process of training and advising local staff.

Because no major modifications, apart from the installation of a computer and the relocation of the processor - from underground to surface - would have been made at the Falconbridge No. 5 Mine, it is expected that the results determined by the end of the first year would very nearly satisfy the original requirements for "pure" signals.

A study of rockbursts in crown pillars, at a mine at which a system is presently installed, would also be initiated as a separate, but related project during the first year.

WORK PLAN: Year 2

By the end of the second year the work at the Falconbridge Mine should have been completed. Afterwards, by mutual agreement, as much of the system as possible could be moved to another mine in the Falconbridge group.

The work at Inco's Creighton Mine would have progressed to the point at which at least some individual signature signals could be identified. The work, in respect of purification of data, should be well advanced.

Simultaneously, the conventional rockburst monitoring system would have been purchased and installed at a specific site.

At the end of the second year, all of the equipment required should have been installed in place and successfully calibrated and made fully operational.

WORK PLAN: Years 3 and 4

During the third and fourth years of the project, the major effort in connection with event recognition would be continued at the Creighton Mine while other case-history studies would be underway at other locations.

Following the establishment of precise specifications, the more sophisticated monitoring system would probably be ordered and installed during the third year.

Monitoring could be continued at the Falconbridge property into which the equipment had been relocated during the second year of the project. At the end of the fourth year of the research it would become clear if further extensions to that system might be required.

WORK PLAN: Year 5

During the final year of the work for this project it is anticipated that the original objective would have been met and that objectives and a plan for on-going studies would be in a stage of development by the project team.

As mentioned previously, it has been suggested that it would be logical for the work to be continued through assessments of the effects of bulk mining methods on local stability conditions. Trials, if not actually underway at this stage (as the result of an agreed-upon acceleration of the work), would at least be at an advanced stage of planning.

With mining at Creighton being likely to continue well into the next century, and with conditions likely to become more difficult at depth, it is probable that the increase in microseismic activity which is anticipated would also result in plans to continue the original work. While it is hoped that a number of the technical problems would have been solved, the aspect of predictability would probably remain as a high-priority key issue.

CONTINUATION PLAN: Subsequent Years

At the end of the five-year period, a well-qualified team with considerable experience in both rockbursts and microseismicity would have been

developed in CANMET/MRL. Because it is certain that rockbursting problems must become more acute as Canadian mining progresses to greater depths and extraction ratios there is no doubt that continuing activity at a high level will be required.

During the next five years it is also likely that increased use will be made of low-cost bulk mining methods in order to effect productivity improvements - which will be necessary to the survival of the industry. The effects of large scale mining on regional stability conditions are not fully known and, consequently, local monitoring will be essential.

With both of the above in mind, then, the steps which have been proposed towards the development of a Canadian expertise will undoubtedly be shown to have been in the national interest.

LIAISON WITH OTHER ORGANIZATIONS

A close technical liaison will be maintained with the Seismology Division, Earth Physics Branch, EMR, which operates the Eastern Canada Seismic Network. Any large rockburst saturates mine microseismic networks, and data acquired through the national seismic network is required for the calculation of magnitude values. It is also visualized that the Earth Physics Branch will be requested to provide analytical assistance.

Close liaison at the working level will be maintained with the Mining Health and Safety Branch of the Ontario Ministry of Labour. That Branch has taken a leading role in advocating the development of monitoring systems in Ontario mines during the past five years, and is involved with rockbursting problems on a daily basis. Their participation is unquestionably "key" to the success of the project.

Regular contacts will be also established with research organizations working on rockbursts in other countries, notably the Chamber of Mines in South Africa and the United States Bureau of Mines. It is also hoped that it may be possible to conclude a joint USBM/CANMET/MOL agreement for the sharing of research results in both ground control and emergency preparedness measures in the near future. Similar agreements already exist in other areas; notably for wire ropes and for diesel emissions.

TECHNOLOGY TRANSFER

Starting in the 2nd or 3rd year of the project, workshops and seminars will be held in the various mining camps. The latest research

results will be explained to the industry, regulatory agencies and other interested organizations. At the end of the 5th year a manual on rockbursts will be prepared.

CO-ORDINATION AND DIRECTION

During the initial stages, in which the project team would be formed, both co-ordination and direction would be provided by a CANMET/MRL team consisting of:

Dr. D. Hedley, Research Scientist, ELL

Mr. G. Larocque, Manager, MRL

Dr. J.E. Udd, Director, MRL

In the very first stages, the work would consist of the ordering and installation of the equipment required. This would be well within the capabilities of the above team.

Additionally, there would be a continuing dialogue with the industrial partners and it might be desirable at an early stage to ask each company participating to provide a representation to sit on an overall steering committee.

With the development of the project team, however, co-ordination of the work would be assumed by this group - which would be situated at the Elliot Lake Laboratory of MRL.

Overall direction would continue to be provided by the original team, to which the professionals working on the project would have been added. Representation would also be sought from other organizations participating in the project, such as: the Ontario Ministry of Labour, INCO, Falconbridge, etc.

APPENDIX "A"

The following is a list of the participants at a CANMET-sponsored workshop "Microseismic Monitoring in Canadian Mines", held in Sudbury, Ontario, on August 14-15, 1984.

Chris Page	Johannesburg, South Africa.
Tony Makuch	Campbell Red Lake Mines, Balmertown, Ontario.
James Willan	McGill University.
Hamish Miller	University of British Columbia, Vancouver.
Dave West	Falconbridge Ltd., Falconbridge, Ontario.
Barbara Welsh	Dickenson Mines, Balmertown.
Ian Clegg	Falconbridge, Ontario.
Ed Berdusco	Algoma Ore Division, Wawa.
Alex Henderson	Lockerby Mine, Falconbridge Ltd.
Jacques Bourbonnais	Roctest Ltd., St. Lambert, P.Q.
John Cook	Lac Minerals, Kirkland Lake, Ont.
Don Bruce	Lac Macassa, Kirland Lake, Ont.
Akbar Sheikh	Denison Mines, Elliot Lake, Ont.
G. Hunt	Denison Mines, Elliot Lake, Ont.
Jim Chandra	Dept. Natural Resources, Fredericton, N.B.
F. Umangay, Jr.	Elliot Lake, Ontario.
P. Oliver	Inco Ltd., Copper Cliff, Ont.
J.A. St. Pierre	Falconbridge Ltd.
H.A. Smith	Falconbridge Ltd.
R.A. Cameron	Laurentian University, Sudbury, Ont.
Frank Ingham	Rio Algom, Elliot Lake, Ont.
Gary Morgan	Rio Algom, Elliot Lake, Ont.
Peter Cain	CANMET/CRL - Cape Breton, Sydney, N.S.
Tom Vladut	CANMET/CRL - Calgary, Alberta.
Charles Graham	Sudbury, Ontario.
Thian Yu	Kidd Creek Mines, Timmins, Ont.
Harald Kanduth	Noranda Research Centre, Pointe Claire, P.Q.
Osman Momoh	Noranda Research Centre, Pointe Claire, P.Q.
Corwin Malott	Electro Lab, Spokane, Washington
Jim Vance	PCS Mining, Saskatoon, Sask.
John Udd	CANMET/MRL, Ottawa, Ontario.
Glen Larocque	CANMET/MRL, Ottawa, Ontario.
Paul MacDonald	CANMET/MRL, Elliot Lake, Ontario.

APPENDIX "B"

Estimated Expenditures by Years

	<u>YEARS</u>				
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
A) <u>Equipment, \$1.4 Million (refer to page 11)</u>					
\$300,000 up-grading INCO and Falconbridge systems		\$200,000 * purchase of a standard system (*includes \$100,000 for local installation)	\$700,000 * purchase of precision system	\$100,000 costs of local installations	\$100,000
B) <u>Human Resources, and equipment maintainance, \$1.4 Million (refer to pages 11-12)</u>					
i) <u>Manpower</u>					
	<u>2 PY</u>	<u>3 PY</u>	<u>5 PY</u>	<u>5 PY</u>	<u>5 PY</u>
	\$100,000	\$125,000	\$225,000	\$225,000	\$225,000
ii) <u>Travel</u>					
	\$40,000	\$40,000	\$40,000	\$40,000	\$40,000
iii) <u>Training</u>					
	\$25,000	\$25,000	---	---	---
iv) <u>Maintenance and contracts for local installations</u>					
	\$50,000	\$50,000	\$50,000	\$50,000	\$50,000
C) <u>Industrial Contributions to support local installations, \$1.4 Million (refer to page 12)</u>					
i) <u>Manpower</u>					
	<u>2 PY</u>	<u>2 PY</u>	<u>2 PY</u>	<u>2 PY</u>	<u>2 PY</u>
	\$80,000	\$80,000	\$80,000	\$80,000	\$80,000
ii) <u>Contributions to cost of project (labour, use of systems, materials)</u>					
	\$200,000	\$200,000	\$200,000	\$200,000	\$200,000